Bridge Deck Cracking Consultant Services

MONTANA DEPARTMENT OF TRANSPORTATION
In cooperation with the U.S. Department of Transportation - Federal Highway Administration

Project Number MDT- 313162
(WJE Project No. 2019.2214)

ITEM 1: SUMMARY PAGE

MDT - 313162 - Bridge Deck Cracking Consulting Services

Proposer: Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Rd.
Northbrook, Illinois 60062
847-272-7400

Person Submitting Proposal: Todd Nelson
330 Pfingsten Rd
Wiss Janney Elstner Associates, Inc.
Northbrook, Illinois 60062
847-753-6583

Proposal Written by: Todd Nelson, P.E. (Illinois), Project Manager and Associate Principal
Paul Krauss, P.E. (Montana), Project Advisor and Principal
Mohamed ElBatanouny, Ph.D., S.E. (Illinois), Structural Engineer and Associate
Elizabeth Nadelman, Ph.D., Materials Scientist and Associate
Eisa Rahmani, Ph.D., Structural Analyst (Modeling) and Associate
Brian Merrill, P.E. (Texas), Project Advisor and Principal

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Principal Investigator: Todd Nelson
330 Pfingsten Road
Northbrook, Illinois 60062
847-753-6583
tnelson@wje.com

Proposed Contract Period: 17 Months

Total Contract Amount: $188.876.08

WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

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ITEM 2: BACKGROUND AND PROBLEM STATEMENT

Background

Early-age cracking of concrete bridge decks continues to be a common issue reported among state departments of transportation (DOTs) and other transportation agencies. In a survey of U.S. and international transportation agencies conducted as part of the NCHRP Report 380, "Transverse Cracking in Bridge Decks," Wiss, Janney, Elstner Associates, Inc. (WJE) found that, on average, transverse cracks initiated within the first month in 53 percent of all bridge decks placed (Krauss & Rogalla, 1996). In the 20+ years since this report, numerous researchers have continued to investigate early-age cracking in bridge decks (French, Eppers, Le, & Hajjar, 1999; Frosch, Blackman, & Radabaugh, 2003; Yuan, Darwin, & Browning, 2011), but cracking still remains a primary issue for new bridges. There are many reasons for cracks to initiate; however, the most common sources of early-age cracking in bridge decks are autogenous shrinkage, thermal-induced contraction, drying shrinkage, and differential drying, as described below.

- **Autogenous shrinkage** is a reduction in concrete volume due to the consumption of water from the capillary pores during cement hydration. Autogenous shrinkage manifests itself at very early ages while the concrete is still developing strength, so relatively small autogenous deformations may generate relatively large tensile stresses compared to the material's tensile strength. Typically, for notable autogenous shrinkage to occur, the concrete must have a w/cm less than about 0.40 (Kosmatka & Wilson, 2016). High-performance concrete (HPC) mixtures with w/cm of 0.35 or less and/or containing fine mineral admixtures such as silica fume are especially susceptible. As HPC has become more common in the construction of bridge decks, autogenous shrinkage and its related cracking have become a greater concern for state DOTs.

- **Temperature changes** in concrete occur as a consequence of cement hydration and daily fluctuations in ambient temperatures. Because the process of cement hydration is exothermic, the temperature of the concrete initially increases while the concrete is still in a plastic state. After setting, the concrete temperature continues to rise until it reaches a peak, typically within the first day or two of placement. As the concrete cools from its peak hydration temperature, it will begin to shrink, generating non-linear temperature gradients and thermal stresses while the concrete's tensile strength is still not fully developed. Cracking during this stage may be very narrow and difficult to see, but these very fine, early-age cracks provide a weakened plane that can widen and extend due to diurnal temperature changes and drying. One of the primary causes of the continued increase in the incidence of deck cracking in the last 20 years is the gradual changes in portland cement chemistry and fineness that result in faster setting and compressive strength gain but also higher heat of hydration. Cement producers claim that it is not cost competitive to provide a coarser, low heat (Type IV) cement due to the lack of demand and existing silo storage procedures. Therefore, engineers are limited to exploring options to mitigate the effects of the currently available cement types.

- **Drying shrinkage and differential drying** can contribute to the early-age cracking of bridge decks. Drying shrinkage is a natural process as the concrete loses moisture to the environment. The loss of moisture in concrete is a two phase process. The first phase consists of loss of free water due to bleeding, which causes little volumetric movement. Inadequate bleeding and high evaporation rates can result in random surface cracks in the plastic concrete. The second phase consists of loss of adsorbed water from the concrete, which results in volume change essentially equal to the volume of water lost. Drying will continue until the available moisture inside the concrete reaches equilibrium with the surroundings. When considering drying shrinkage of bridge decks, not only does the bulk volume change have to be considered, but also the volume change caused by differential drying. Typically, the exposed surfaces of a bridge deck will dry faster than the center, creating a differential drying gradient through the concrete's thickness. When this occurs, the exposed surface will shrink more than the central region, creating stress gradients. The stresses developed in bridge decks resulting from differential drying can be very large but are often reduced by concrete creep.

The potential for cracking in bridge decks is also affected by the restraint of the concrete. This restraint comes in many forms. For bridge decks, the primary sources of restraint are composite girders, such as stirrups protruding from prestressed concrete girders or shear connectors attached to steel girders, and the reinforcing steel which restrains bulk volumetric changes in the deck. Because such restraint conditions are largely unavoidable, commonly employed crack mitigation methods tend to focus on reducing the effects of volume change mechanisms of the concrete not deck restraint.

Cracking commonly leads to a reduction in service life and increased maintenance costs, primarily due to accelerated corrosion of reinforcing steel in the deck and substructure but occasionally due to structural failure of the deck. Identifying the causes of bridge deck cracking and providing prevention can be complex and challenging but is very important for maintaining longevity of the bridge deck.

Previous Work

In June 2016, Montana Department of Transportation (MDT) noted severe cracking on two bridge decks in the Missoula District along Interstate 90. Both bridges exhibited closely spaced transverse cracking through the full thickness of the deck, which led to holes in the deck after small sections of the concrete deck fell through. The decks for these bridges were relatively new, having been replaced in 2010 and 2011. Further review of additional bridge decks in western Montana by MDT, staff revealed widespread transverse cracking in more than 20 additional bridge decks constructed within the previous 10 years. Many of these bridge decks were along Interstate 90 and represented replacement decks over existing bridge substructures originally constructed between 1960 and 1980. In all cases, the concrete bridge decks were composite with either prestressed concrete beams or wide flange steel plate girders, but the span lengths and deck thicknesses varied, as did the cementitious composition of the concrete mix designs.

In August 2016, MDT commissioned WJE to perform a detailed investigation to identify the root cause(s) of the bridge deck cracking in the Missoula District bridges and provide recommendations for improvement. WJE's investigation consisted of:

- A review of documentation related to the western Montana bridge decks, including plan drawings, specifications, concrete mixture proportions, quality control results, and photographs of bridge decks experiencing severe cracking distress and those experiencing little distress;
- In-depth field assessments of four bridge decks and cursory comparative assessments of eight nearby bridge decks representing a range of crack severity, age, and cementitious materials contents;
- Laboratory evaluations of concrete cores sampled during the in-depth investigations to determine mechanical performance and to identify any materials-related distress; and
- Analytical studies to evaluate the influence of ambient temperature, concrete placement time, concrete compressive strength, deck thickness, and substructure geometry on early-age stresses generated in the bridge decks.

The most prominent cracking feature observed during WJE's field investigation were closely spaced transverse cracks, which subsequent laboratory testing and analytical studies indicated initiation at very early ages primarily due to thermal changes within the bridge deck; additional stresses generated by drying and autogenous shrinkage likely further contributed to crack-generating stresses, crack growth and extension, and eventual deck failure. WJE made the following primary recommendations to modify concrete curing and placement procedures for new bridge decks with the intent of reducing early age transverse cracking:

1. Immediately fog-mist concrete placements until wet curing media is in place to provide surface evaporation and to cool the concrete.*
2. Monitor concrete temperatures and apply insulation blankets when peak hydration temperatures are obtained to insulate the deck from the environment, improve strength gain and curing, and slow the rate of cooling; thus, decrease the early age tensile stress development. See Figure 1 for idealized effect of the addition of the insulation blankets.*
3. Consider placing concrete in the late afternoon or early evening, preferably between 4 and 8 pm, to avoid peak concrete temperatures occurring just prior to cool evening hours. This recommendation provides benefit as the ambient cooling and cooling from peak hydration do not coincide. In addition, the strength development at the time of cooling is higher. Both of these reduce the early age tensile stress development. See Figure 1.
4. Limit plastic concrete temperature at the time of placement to less than 75 °F, or as cool as practical, to reduce the heat of hydration of the concrete.

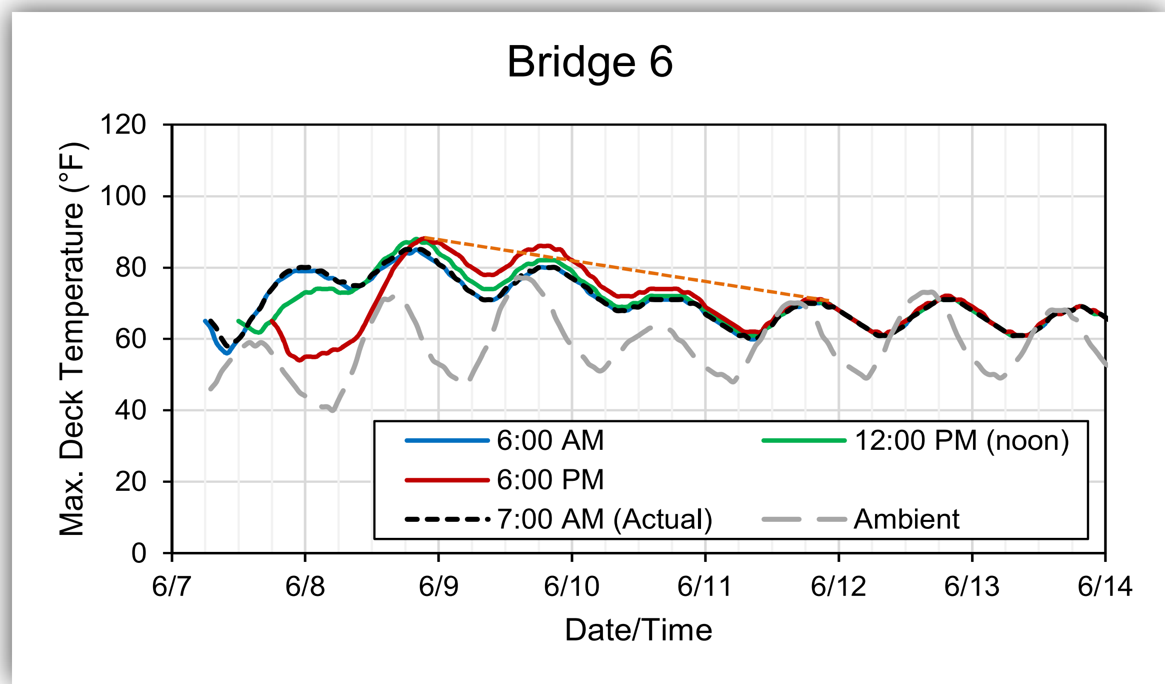


Figure 1. Modeled concrete deck temperatures during WJE's investigation in 2016 showing the effect of placement times and application of curing blankets. When the placement times are shifted to the afternoon (red line), peak concrete temperatures are delayed as cool evening (first night) ambient temperatures offset hydration heat and allow increased concrete strength prior to cooling. The idealized effect of the application of the insulation blankets is shown by the orange dotted line.

Additional secondary recommendations were also provided:

5. Increase design deck thickness to a minimum 8 inches to reduce the effects of non-linear temperature and drying profiles and associated stresses at the top and bottom of the deck.*
6. Modify specifications to require staggering of top and bottom transverse reinforcing mats to reduce the alignment that facilitated formation of full-depth cracks and holes.*
7. Limit cementitious materials content to no more than 600 pounds per cubic yard to reduce autogenous shrinkage, drying shrinkage, and total heat of hydration.*
8. Limit silica fume replacement to 5 percent to reduce the potential for autogenous and plastic shrinkage cracking.*
9. Specify a w/cm for deck concrete between 0.42 and 0.45 to ensure adequate concrete durability without increasing the risk of autogenous shrinkage.*
10. Consider optimizing aggregate gradations to reduce paste volume and cracking tendency.

Problem Statement

Based on discussions with MDT personnel, we understand that the recommendations indicated above with an asterisk (*) have been implemented by MDT on subsequent bridge deck construction projects since 2016. MDT personnel have reportedly observed a notable decrease in early-age cracking due to these changes, but additional investigations are needed to further assess the benefits of the modified mix designs, placement procedures, and curing procedures. With additional investigations, MDT can determine which implemented recommendations have led to the greatest improvements in early-age cracking reduction.

To answer these questions, MDT has requested a follow-up study to quantify the relative impact of each implemented recommendation in order to better understand which recommendations have been most important in reducing early-age deck cracking. To meet this primary objective, WJE has proposed a multi-disciplinary approach including field investigations, bridge instrumentation, laboratory studies, and analytical modeling; as described below:

1. Review available documentation from recent bridge deck construction projects to identify which recommendations were implemented. Review documentation of and conditions of the newly constructed bridge decks built with WJE's recommendations.
2. Perform a detailed inspection of recently constructed bridge decks (with implementation of WJE's recommendations) to quantify the type, amount, and extent of distress, if any, present on the decks, and compare the results (where appropriate) to distress previously observed by WJE on bridge decks of similar age and environmental exposures.
3. Through field, laboratory and analytical investigations, evaluate the relative effects of concrete materials, construction practices, deck design practices, and environmental factors on the cracking related performance of recently constructed bridge decks.
4. Through analytical modeling, thoroughly review all recommendations and assess the significance of each and assess any further potential for cost-effective solutions to reduce early-age bridge deck cracking.

ITEM 3: BENEFITS OF RESEARCH

Reducing the incidence of cracking in newly constructed bridges decks by simply modifying the deck curing process provides obvious benefits for state transportation agencies. Cracking allows deicer solutions and carbon dioxide direct access to embedded reinforcing steel and the tops of steel girders, bypassing the engineered cover of low permeability concrete. Not surprising, investigations of aged bridge decks find that corrosion and related damage occurs first at crack locations, even when the reinforcing steel is epoxy-coated. Reducing cracking in new bridge decks will reduce needs for future maintenance and extend the service life of decks significantly, easily doubling the time before rehabilitation is needed.

Contractors also benefit from the revised curing procedures that have been proposed by WJE since the curing period is shorter than the standard 14 days, decks can be returned to traffic sooner, and less cracking reduces their risk. Once contractors have experience with the modified procedures, the costs involved for curing should not increase over current curing practices and might be less than current practices.

Montana DOT efforts to reduce deck cracking are applicable nation-wide, further maintaining Montana DOTs reputation as leaders in bridge preservation.

ITEM 4: TASKS - RESEARCH PLAN

Item 4.1 - Literature Review

WJE will utilize its extensive library capabilities to conduct a thorough review of current available research regarding early-age transverse cracking of concrete bridge decks. Performance of existing bridge decks in states such as Minnesota, Kansas, New Jersey, and Indiana, who have also conducted research efforts to mitigate early-age bridge deck cracking, will be compiled to ascertain the relative effectiveness of the proposed recommendations. In addition, the literature review will build on this research, including early age cooling effects and associated stresses, of the recommendations proposed by WJE in the previous investigation. WJE will also perform a review of current MDT bridge specifications, concrete mixes, and records of historic performance (e.g. strength development), with the intent of identifying (1) mixtures and material combinations most likely to contribute to or avoid increased early-age cracking, and (2) current handling, placement, and/or curing practices that may be modified to further reduce the likelihood of early-age cracking. While deck cracking has been avoided at early-ages by using the modified curing, cracking has occurred before one year of exposure. Therefore, longer-term seasonal effects on cracking risk will be investigated also. WJE will review documentation of previously constructed bridge decks and correlate to the time of year, sequencing of placements, and location of cracking severity. WJE to also provide additional literature review on modeling techniques for varying restraint conditions, long term drying and thermal effects along with dynamic mechanical behavior (fatigue).

WJE maintains a current technical reference library, including over 24,000 reference books, journals, and WJE report files for the engineering practice of the company. WJE has two dedicated staff librarians perform research and handle interlibrary loans. The Library maintains contact with other specialized libraries (such as the Portland Cement Association Library) and academic libraries (such as Northwestern University Library) and is a participant in the worldwide interlibrary loan system. WJE Librarians have access to online abstract services and engineering citation databases to thoroughly identify current articles related to all project capabilities.

Item 4.2 - Data Accumulation

To support the investigation, data will be accumulated from the documentation of recently constructed bridge decks that have utilized WJE's previous recommendations, constructed between 2015 and 2018. This documentation will include project drawings, specifications, implemented recommendations, concrete mix designs, concrete batch tickets, concrete quality control records, temperature monitoring data, and previous condition documentation (crack mapping, photographs, etc.). For the bridge deck instrumented in ***Item 4.4b***, Page 9, documentation will include concrete mix designs, drawings, specifications, concrete testing data, and construction schedule.

Item 4.3 - Evaluations of Data

The provided data will be evaluated to further aid in development of the field, laboratory, and analytical studies; selection of bridges to be inspected; defining the instrumentation plan; and defining variables in the finite element modeling. WJE and MDT will have a meeting to discuss the evaluated data and develop a plan for the following:

- Bridges to be inspected for ***Item 4.4a.***
- Instrumentation plan for ***Item 4.4b.,*** Page 9
- Any modifications to the schedule and proposed scope of work.

Item 4.4a - Bridge Deck Inspections

Bridge inspections are proposed on new bridges constructed using WJE's previous recommendations. This will help WJE evaluate the efficacy of previous recommendations and potentially guide additional field, laboratory, and analytical studies. WJE proposes to investigate bridges in the fall/winter of 2019 and in the spring/summer of 2020. The goal for the fall/winter 2019 investigations is to select three to four bridge decks constructed in 2019 with WJE's recommendations. As a follow-up to these 2019 bridge inspections, these same bridges (along with possible other candidates) will be inspected in the spring/summer of 2020 in order to assess the progression of the cracks over the first 6 to 9 months and exposure to a winter season. It is anticipated that the 2019 bridge inspections will be performed during the same week as the instrumented bridge in ***Item 4.4b***, Page 9, either before or after the instrumentation. It is anticipated that the bridge inspections will take two to three WJE staff members approximately 2 to 3 days to complete. The inspections are anticipated to include the following:

- A visual survey of the top side and under side (when accessible) of each deck will be performed. This survey will focus on locating and documenting the extent, nature, and location of deterioration. Types of visually, identifiable deterioration include cracking, spalling, corrosion staining, scaling, abrasion, spalling, efflorescence, and other distress will be documented. Photographs of representative distress will be taken. Detailed crack mapping will also be performed on the top side of representative areas, documenting the location and size of cracks.
- A delamination survey will be performed on representative areas on the top side of the deck, using chain dragging and hammer tapping. The location and size of any delaminations will be documented.
- If cracks are found, WJE will identify core locations for concrete sampling for subsequent laboratory studies. These cores will be located strategically to capture the crack or distress mechanisms and be representative of the findings of the visual and delamination surveys. It is assumed the MDT will commission a coring contractor to extract the cores and patch the core holes. If needed, the concrete cores will be extracted to evaluate crack characteristics and general concrete quality utilizing petrographic methods in accordance with ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete*.

Similar to the 2016 inspections, all of the field measurements, observations, photographs, and core locations will be documented and collected on WJE's Plannotate software. WJE has developed general field inspection and bridge-specific software using the Plannotate software. Field use has demonstrated the system to be an efficient platform for collection and review of field inspection data. Frequent uploads of the collected information to WJE's servers help prevent any loss of the inspection data. The basis of the inspection process is to tie the inspection notes and photographic documentation spatially to the relevant bridge documents using WJE Plannotate iPad software. The field inspection notes and photographs are available to MDT in near real-time for review in most Internet connected web browsers. The inspection data is accessible for quality assurance purposes by ensuring that significant findings and recommendations are fully supported by field documentation prior to leaving the site. WJE's Plannotate engine also allows MDT to store the inspection results (cracking, delaminations, photographs, petrography, chloride contents, etc.) in a database that can be used for future inspection comparisons or quantification of the data. Since the previous inspections were also documented in Plannotate, comparisons of the newly constructed bridge decks can be easily compared to the previous inspection data.

Item 4.4b - Instrumentation of Bridge Deck

To achieve a better understanding of early age strains, stresses, and temperatures in Montana bridge decks, WJE proposes to instrument one new bridge deck with thermocouples and strain gages at various sections that represent different boundary conditions and anticipated deck strains and to monitor the bridge over the winter season. As part of ***Item 4.3***, Page 8, WJE will review the documents provided by MDT regarding the design and construction of the new bridge decks. Based on this review, WJE will prepare and submit an instrumentation plan to MDT for review and approval. WJE will also attend the preconstruction meeting to discuss the work plan and schedule with all involved parties including MDT personnel and the Contractor's staff.

WJE proposes to instrument four locations on one deck placement with locations being at the beginning and end of the concrete placement including edge and perimeter conditions. At each section, WJE will embed five thermocouples at different depths of the deck to obtain the temperature profile. In addition, WJE proposes to measure the temperature of the supporting girders, assuming the girders are accessible. WJE will also embed three vibrating wire strain gages at each section; two near top and bottom surfaces and one at mid-depth. Vibrations wire strain gages (VWSGs) were chosen for this purpose due to their successful track record when embedded in concrete. WJE has used similar setups in new bridge decks construction to measure early age strains and temperatures. The instrumentation will also include the measurement of internal concrete relative humidity at three depths through cross-section of the deck to assess the long-term effects of drying. In addition to the embedded sensors, WJE will also measure the ambient temperature, relative humidity, and wind speed during the monitoring period. It is anticipated that the deck instrumentation will be monitored for a period of approximately 6 months.

All of the instruments will be connected through multiplexers to a Campbell Scientific data logger that will record the temperature and strain data at specified intervals, one measurement every 5 minutes is currently proposed. Since the monitoring will continue through the winter season, specialized data loggers and multiplexers will be purchased to operate at very low temperatures. The system will include a communication device (cellular modem) for remote connectivity, which can be accessed by MDT and WJE personnel at any time. Solar panels and backup batteries will be used to provide electrical power for the system and associated backup. It is anticipated that two WJE employees will install and test the system in four to five working days prior to concrete placement. We anticipate coordinating with the contractor to limit interference and construction schedule. During the concrete placement, it is anticipated that at least one WJE staff will be on-site until the insulation blankets are applied.

The data generated from the field monitoring will be used to verify and calibrate the finite element modeling performed in ***Item 4.5*** of this proposal. Recording and analyzing actual in-place concrete temperature and strain is important for achieving the goals listed in **Item 2,** Page 6, and applying significance to WJE's previous recommendations.

Item 4.5 - Finite Element Modeling

Three-dimensional finite element (FE) models will be developed to simulate effects of all the recommendations and associated variables on performance of concrete decks at early ages. The primary goal of the modeling will be to assess the significance of WJE's primary recommendations. Specifically, the modeling will be performed to perform a sensitivity analysis on the following:

1. The effect of early age wet curing.
2. The effect of timing of the application of insulation and insulation value (R-Value).
3. The effect of varying the concrete placement times.
4. The sensitivity to deck thickness, mix properties, plastic concrete temperature, seasonal temperature variations, girder temperatures, and drying shrinkage.
5. Concrete age at initiation of drying and effect of curing compound application.
6. Other variables may be analyzed depending on the outcomes of the document review, field investigations, deck instrumentation, or initial modeling results.

All FE analyses will be conducted using the commercial finite element program Abaqus. In the last 10 years (Biggs, 2000) (Dekelbab, Hendriks, & Witasse, 2005) (Hopper) (Liu, 2018) (Wan, 2010), the FE methods have shown the capability to effectively estimate thermally-induced stresses within concrete bridge decks allowing a significant number of analyses to be performed in lieu of experimental and field testing. The proposed FE analyses will estimate the deck stresses induced by the through-thickness thermal gradient caused by the hydration heat of the newly placed concrete decks and the ambient temperature. The maximum principal tensile stress will be the primary metric for assessing the effect of various environmental, construction, and design factors. The proposed FE model will be constructed using bridge drawings from MDT simulating the instrumented decks in ***Item 4.4b***, Page 9. This model will include the geometry of a bridge segment that consists of details of concrete deck, steel rebar, and a girder beam. Other common deck geometries can also be investigated.

In order to accurately model early age stresses in the bridge deck, the following laboratory testing is proposed on the concrete mix used for the instrumented and modeled bridge deck. This laboratory testing will supplement and verify the FE modeling of the bridge deck.

- The early and late age development of compressive strength (AASHTO T22), splitting tensile strength (AASHTO T198), and modulus of elasticity (ASTM C469) will be measured. It is anticipated that these measurements will be made at 24 and 72 hours after fabrication, with later ages also being tested at 5, 28 and 90 days. Based on the testing, maturity curves will be developed as a function of each of these physical properties in accordance with ASTM C1074, *Standard Practice for Estimating Concrete Strength by Maturity Method*. As a function of maturity, the FE model can accurately account for early age development of physical properties.
- Drying shrinkage and effect on cracking will be measured with drying starting at 5 and 14 days after fabrication when wet curing is removed, consistent with the initiation of drying using WJE's recommended curing procedures and with MDT's previous wet curing procedures, respectively.
- Concrete creep will be measured at 5, 28, and 90 days after concrete fabrication in accordance with ASTM C512, *Standard Test Method for Creep of Concrete in Compression.* The creep coefficient will be calculated and implemented in the model for reduction in stresses.
- The Coefficient of Thermal Expansion (CoTE) will be measured in general accordance with AASHTO T336, *Standard Test Method for Thermal Coefficient of Thermal Expansion of Hydraulic*

Cement Concrete. It is proposed to perform CoTE on the concrete within 5 days after fabrication and at 28 days.

- Semi-adiabatic temperature rise will be measured on the mix in order to capture the heat generation and be used to calibrate the FE model for early age thermal temperature rise.

Item 4.6 - Reporting

During the duration of the project, monthly progress and Task reports will be delivered to MDT, as further described in (**Item 7**, Page 12). At the conclusion of the investigative work proposed above, WJE will compile a comprehensive report including the completed scope of work, findings, recommendations, and implementation. The details of the reporting are further discussed in the deliverable portion of this proposal (**Item 7**, Page 12).

ITEM 5: DATA

The provided data will be compiled in an organized, electronic format, and the source of each document will be clearly identified. All data will be provided to MDT via a secured source at the completion of the project, similar to the 2016 investigations performed by WJE.

In addition to WJE's report being inclusive of all the data from this study, the field investigation data will be preserved in WJE's Plannotate software. Collection of field data has always been a core component of WJE's project work. In an effort to enhance data collection techniques, as previously discussed, WJE developed Plannotate, a software application to annotate inspection data onto PDF's using the Apple iPad. The inspectors' data is stored in an open mapping data format that allows for simple aggregation and analysis in programs like Excel. This mapping provides information on the appearance and spatial position of the annotation, as well as inspection data and photographs collected by the inspector. This data will always be available to MDT and can be used for future inspection documentation.

ITEM 6: MDT INVOLVEMENT

Based on the scope of work presented above, WJE would request assistance from MDT on the following tasks. WJE will communicate directly with MDT with specific and detailed requests and in monthly reports:

- For ***Item 4.2***, Page 7, collection of documentation related to the construction of bridge decks that that were cast using WJE's previous recommendations (to be inspected in ***Item 4.4a,*** Page 8): project drawings, specifications, implemented recommendations, concrete mix designs, concrete batch tickets, concrete quality control records, temperature monitoring data, and previous condition assessments (crack mapping, photographs, etc.).
- For ***Item 4.4a***, Page 8, scheduling of lane closures for bridge deck inspections and coring services. It is anticipated this will take two to three days to perform the inspections and associated coring.
- For ***Item 4.4.b***, Page 9, collection of documentation related to the construction of the two new instrumented bridge decks: concrete mix designs, drawings, specifications, concrete testing data, and construction schedule.
- For ***Item 4.4b***, Page 9, assistance with collection and shipment of raw materials for the laboratory trial batching of the concrete used on one of the instrumented bridge decks, as needed to support the FE modeling. Assistance would include identification of sources and contacts for the raw materials to be used on one of the instrumented bridge decks, preferably the first instrumented deck.

ITEM 7: MEETINGS AND DELIVERABLES

Meetings

WJE proposes an initial Kick-Off meeting with MDT prior to initiation of **Item 4,** Page 7, of the proposed scope of work. This meeting is proposed to be held via web meeting/conference call, and the goal of this meeting will be to introduce WJE's team to MDT; discuss the proposed scope of work and schedule; and discuss documentation related requests. At the completion of ***Item 4.3***, Page 8, a meeting will be held with MDT and WJE to discuss the data evaluations. WJE also proposes an on-site preconstruction meeting prior to the bridge instrumentation installation; after completion of the bridge deck instrumentation and monitoring period; Implementation Meeting, and during the Final Reporting process. The Implementation meeting has been planned to coincide with the Oral Presentation. The project manager and additional appropriate WJE staff will attend each of these meetings, and meeting minutes will be provided for review within two weeks after completion of the meeting.

Deliverables

Monthly Reports

Monthly progress reports are proposed to be delivered to MDT prior to the 15th of every month. These progress reports will include updates on scope completion; upcoming schedule; requests for MDT involvement; overall percentage completion (% of overall budget) and current invoice; and any upcoming concerns and resolutions.

Task Reports

Task reports will be issued at the completion of each Item. When these Task reports coincide with a monthly report, only one Task report is proposed. These reports will be written in a fashion to be easily included in the Final Report and will include all the information in the monthly progress reports and include the following: task summary, major findings, and any associated implementation opportunities. WJE anticipates these Task reports will be brief in nature ~ 2 to 3 pages in length.

Final and Implementation Report

The Final Report will be submitted in Microsoft Word and Adobe Acrobat format and prepared in accordance with Montana Department of Transportation's Report Writing requirements. All data will be presented in metric units with the English units in parentheses. The final reporting for this project will be delivered to MDT in Draft form for review and comments. After comments are addressed by WJE's project manager and appropriate staff, a second draft will be delivered to MDT within two weeks of receiving MDT's comments. Any additional revisions will be delivered within a week of MDT's comments. After the completion and approval of WJE's Final Report, WJE plans to provide an Implementation report (two weeks after the Implementation meeting), Project Summary Report and Oral presentation. WJE has assumed the Oral presentation will be held in Helena, MT.

ITEM 8: SCHEDULE

The time required to complete the proposed scope of work is 17 months, with specific Item durations outlined in the following tables. WJE anticipates providing monthly progress and Task reports during each for ***Items 4.4 and 4.5***, and completing a Final report, Implementation report, and Oral presentation at the completion of the project.

Table 1 and 2. Item and Deliverable Schedule

	2019					2020											
Items	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
4.1 Literature Review (WJE)	X	X	X	X	X	X	X	X	X	X	X	X					
4.2 Data Accumulation (MDT)	X	X	X				X	X	X								
4.3 Data Evaluation (MDT and WJE)		X	X					X	X								
4.4a Bridge Inspections (WJE)					X					X	X						
4.4b Bridge Instrumentation and Monitoring (WJE)					X	X	X	X	X	X	X						
4.5 Finite Element Modeling and Laboratory Evaluations (WJE)		X	X	X	X	X	X	X	X	X							
4.6 Final Reporting (WJE)													X	X	X	X	X

	2019					2020											
Deliverables	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Kick Off Meeting	X																
Meeting for Item 4.2 and 4.3		X															
Preconstruction Meeting (onsite) - Item 4.4a					X												
Meeting after Task report 4.4								X									
Meeting after Task report 4.5											X						
Monthly Progress Reports	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Task Reports						**4.4**	**4.4**	**4.4**	**4.5**	**4.5**							
Final Report													X	X	X	X	X
Implementation Report and Meeting															X	X	X
Project Summary Report															X	X	X
Presentation																	X

ITEM 9: STAFFING - PROJECT TEAM

The Project Manager has carefully selected the following relevant experts for the proposed scope of work and have submitted detailed resumes via the eMACs for this project, which will lend more detail to their background and experience. Three of the members of the proposed Project Team performed the investigations, analyses, and reporting of MDT bridge decks in 2016: Todd Nelson, Paul Krauss, and Elizabeth Nadelman.

For all proposed project staff members, the hours per item/task and percentages of time committed over the duration of the project are presented in the following table.

Table 3. Staffing Time Commitment

Effort By Tasks (Hours) - MDT - 313162 Bridge Deck Cracking Consultant Services									
Principal Staff Members	Role in Study	% Time over Contract Period	Hours						
			Item 4.1	Item 4.2	Item 4.3	Item 4.4	Item 4.5	Item 4.6	Total Hours
P. Krauss	Project Advisor / Materials Engineer	2.8%	5	2	2	12	4	18	43
B. Merrill	Project Advisor / Structural Engineer	1.2%	4	2	2		2	8	18
T. Nelson	Project Manager / Materials Engineer	9.4%	8	2	4	90	5	35	144
M. ElBatanouny	Structural Engineer	8.8%	4			92		38	134
E. Nadelman	Material Scientist	10.8%	24	16	8	64	12	42	166
E. Rahmani	Structural Analyst	15.4%	12		2		200	22	236
L. Zegler	Laboratory Technician	0.5%					8		8
R.Schulman	Field Technician	7.2%				110			110
M.Haddad	Laboratory Technician	1.0%					16		16
Project Totals			57	22	18	368	247	163	875

Todd Nelson, PE | Materials Engineer | *330 Pfingsten Road, Northbrook, IL* | *847.753.6583*

Mr. Nelson will serve as project manager and will handle the day-to-day communication with MDT, scheduling, and coordination. Mr. Nelson has over 18 years of experience in a wide variety of field, laboratory, and analytical investigations of new and existing structures and has worked with MDT for over ten years on concrete troubleshooting, laboratory evaluations, and bridge durability. His experience includes construction materials evaluation, durability assessments, litigation support, laboratory test programs, repair and rehabilitation, and research and development of construction materials. Mr. Nelson's project work has included investigations of concrete slab-on-ground and pavement distress; concrete durability and deterioration of bridge decks; low and variable concrete strength; alkali silica reactivity (ASR); chemical and environmental attack of concrete; and utilization of petrographic, chemical, and analytical diagnostic methods.

Paul Krauss, PE | Project Advisor / Materials Engineer | *330 Pfingsten Road, Northbrook, IL* | *847.753.6583*

Mr. Krauss will serve as a project advisor and will be responsible for technical review of all tasks and reporting. Mr. Krauss has 40 years of experience related to concrete testing and most aspects of concrete construction and rehabilitation and has worked with MDT for over 20 years on projects such as high performance concrete, alkali-silica reactivity, and bridge durability. He has been involved in field investigations and laboratory research for numerous construction failures and problems involving concrete, steel, polymer concrete, coatings, and sealers. He routinely uses structural instrumentation, nondestructive testing, and laboratory testing to solve complex materials problems. Mr. Krauss has been project manager for many research projects involving solutions for bridge deck cracking, corrosion resistant steel, and concrete durability. These studies were conducted for many notable organizations such as the National Cooperative Highway Research Program, Concrete Reinforcing Steel Institute (CRSI), and Federal Highway Administration (FHWA).

Brian Merrill, PE, (TX) | Project Advisor / Structural Engineer | *9511 N Lake Creek Pkwy, Austin, TX* | *847.753.6583*

Mr. Merrill will serve as a structural advisor for this project and will provide technical review on all structural aspects. Mr. Merrill has more than 35 years' experience as a structural engineer. He joined

WJE's Austin office as an Associate Principal in 2013 where he focuses on large structural systems, including bridges, parking structures, wharves, and piers. Mr. Merrill has spent almost 25 years assessing existing structures and their issues and has significant experience with structural assessment, repairs and rehabilitation, forensics, research, and concrete material issues. His background includes 10 years of bridge design work and more than 20 years of bridge construction and maintenance experience. Prior to joining WJE, he served the Texas Department of Transportation for 27 years, the last 13 of which he was the State Bridge Construction & Maintenance Engineer.

Elizabeth Nadelman, PhD | Material Scientist | *330 Pfingsten Road, Northbrook, IL* | *847.753.6395*

Dr. Nadelman will serve as a materials consultant on this project and perform document review, field inspections, and reporting. Since joining WJE in 2016, Dr. Nadelman has been involved in a variety of projects involving the field, laboratory, and analytical investigation of reinforced concrete materials and structures. Her background and interests include durability of concrete materials, service life analysis of reinforced concrete structures, and development and testing of construction materials. In addition to concrete, Dr. Nadelman's experience also includes evaluation of grout, mortar, masonry, and polymeric construction materials. Prior to joining WJE, Dr. Nadelman conducted research at the Georgia Institute of Technology focused on the early-age properties and long-term durability of concrete made with portland limestone cement. She has presented, published, and lectured on her work relating to chemical and autogenous shrinkage, physical salt attack, and transport properties of cement-based materials.

Mohamed ElBatanouny, PhD, PE, SE | Structural Engineer | *330 Pfingsten Road, Northbrook, IL* | *847.753.6395*

Dr. ElBatanouny will serve as a structural engineer and instrumentation consultant for this project and perform field instrumentation and associated reporting. Since joining WJE in 2015, Dr. ElBatanouny has worked on a variety of DOT projects, including field investigations, vibration analysis, and structural health monitoring and instrumentation. He has background and interest in condition assessment of existing structures, nondestructive evaluation, concrete material degradation, load testing, and experimental characterization. Dr. ElBatanouny has managed and served on numerous sponsored research projects. He has authored over 60 publications including two book chapters and has presented numerous lectures. Dr. ElBatanouny is an active member in several technical committees in ACI and TRB.

Eisa Rahmani, PhD | Structural Analyst | *330 Pfingsten Road, Northbrook, IL* | *847.753.6571*

Dr. Rahmani will serve as the structural analyst on this project and perform finite element modeling and associated reporting. Dr. Rahmani's primary interest is in finite element modeling and analysis of structural systems composed of various civil, structural, and mechanical engineering materials such as reinforced concrete, steel, asphalt concrete, and granular materials. Since joining WJE, Dr. Rahmani has been involved in multiple projects involving structural analysis and evaluation, and condition assessment of a wide variety of structures using nonlinear finite element analysis, classical methods, and industry design codes. Dr. Rahmani has been using Abaqus finite element software since 2011 and he has experience with ATENA structural analysis software for reinforced concrete. Dr. Rahmani's graduate work focused on the numerical modeling and laboratory calibration and validation of damage behavior of asphalt concrete materials under environmental effects. He has published papers in various engineering journals and conference proceedings.

ITEM 10: COMMUNICATION AND QUALITY CONTROL

The project manager will maintain day-to-day contact with team members and with MDT. During the initial stages of this project, WJE will work closely with MDT to develop the project objectives, stay on schedule, and to help MDT implement recommendations. The project manager will be responsible for organizing the work in the most cost-effective manner and seeing to those agreed-upon budgets and schedules being maintained.

WJE has a long and proven track record of accomplishing projects in time, within stated budget limitation, and with effective quality assurance. Our record on previous projects for Federal, State, municipal agencies, and the private industry has been and remains excellent. WJE has developed working knowledge of basic and complex investigation or rehabilitation procedures for bridges and uses this knowledge when establishing investigations, scheduling, reporting and implementation of related services.

Quality Control of WJE work product is assured through a consistent technical review and checking process which is applied to every project. This is standard practice on all WJE projects. Two project advisors have been assigned to the project to provide technical review of all deliverables: Paul Krauss and Brian Merrill. The assigned project manager will be responsible, in consultation with MDT's manager, for setting up a formal project / task assignment performance review, and reporting procedures. All work will be reviewed and reported on a regular, periodic basis to avoid pitfalls and to make certain that the objectives of the given effort are met in a timely and cost-effective manner.

ITEM 11: COMPANY/INDIVIDUAL PROFILE AND EXPERIENCE

Wiss, Janney, Elstner Associates, Inc. (WJE) is a professional firm providing practical, innovative, and technically sound solutions to structural, architectural, and materials problems. WJE specializes in the investigation, analysis, and design of repairs for distressed conditions in bridges and other structures. Since 1956, WJE has served more than 70,000 clients around the world from individuals to large corporations and governmental agencies. WJE employs more than 700 experts and support personnel experienced in structural, architectural and civil engineering, as well as petrography, testing and instrumentation. Besides breadth of experience, WJE staff members offer a strong track record of accomplishment in their fields. More than half of the WJE professional staff have over fifteen years of experience, both on-site and in the laboratory. WJE is routinely called upon by state DOTs to provide expert services in the area of bridge inspection, repair, concrete corrosion, and materials investigation. WJE has conducted investigations on a variety of bridge structures in nearly every state in the union.

Specialized bridge services include:

- Investigations of failed or distressed structural systems
- In-depth inspection of corrosion damage and general conditions in reinforced concrete structures
- Material evaluation durability, performance, and for service life modeling
- Nondestructive testing concrete bridge sub- and super-structure
- Field instrumentation and testing of structural systems
- Laboratory testing of structural models, components, and materials used in bridge construction
- Structural analyses and load rating
- Structural repair design and preparation of drawings and specifications for rehabilitation and repair
- Corrosion protection recommendations for concrete structures
- Laboratory evaluation concrete of utilizing petrography, chemistry, and other analytical tools
- Installation and field testing of repair details and procedures to assess their constructability and performance

WJE is uniquely qualified to provide MDT with engineering solutions of these bridge structures. Knowledge of structural behavior and performance of construction materials is supported by technical expertise in testing and instrumentation. The office and laboratory headquarters complex in Northbrook, Illinois, offers 80,000 square feet of state-of-the-art structural and materials test facilities and equipment for construction-related investigations, instrumentation, and research. Clients rely on WJE's more than 60 years of investigation experience to solve problems that arise during and after construction. WJE has demonstrated that research knowledge and laboratory techniques can be put to practical economical use to solve our client's problems. In this way, WJE has earned a reputation for functional, durable, and cost-effective designs.

Bridge Inspection, Evaluation and Rehabilitation Experience

WJE staff members have extensive experience conducting field investigations of bridge deck, superstructure and substructure problems, as well as performing laboratory studies of a wide range of bridge materials. WJE has evaluated problems on bridge types ranging from archaic concrete arch bridges and steel bridge structures to historic bridges to modern high performance steel bridges and long span precast, segmental concrete bridges, as examples. WJE has investigated problems in all types of bridge construction.

WJE has the in-house personnel and expertise to respond to the unique requirements of each bridge investigation. Services include visual inspections, nondestructive and destructive field evaluations, instrumentation and data acquisition, full-scale load testing, laboratory analyses and testing of materials and members, computer analysis of the original design and the as-built structures, design of repairs, field evaluation of trial repairs, and, in some instances, the actual installation of the repairs.

Annually, WJE staff perform more than 250 bridge projects, nearly all dealing with distress and deterioration of critical bridge components, systems and subsystems. Work is conducted for state departments of transportation, local government agencies, and private bridge owners.

Polymer Concrete Overlay Experience - WJE is the industry leader in concrete technology, having completed numerous research and training projects on concrete deterioration, repair, preservation for the American Concrete Institute, Federal Highway Administration, National Highway Cooperative Research Project, Concrete Reinforcing Steel Institute and others. This work has positioned WJE at the forefront of bridge deck rehabilitation.

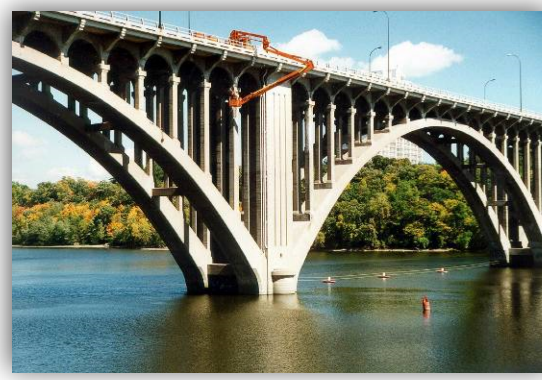
Through a better understanding of the causes of concrete deterioration, WJE has developed repair and rehabilitation solutions that range from sealers and surface treatments that inhibit the ingress of corrosion chemicals such as chlorides; partial and full depth patching using specialized mortars that maximize the effectiveness of these materials to improve long term durability of concrete repairs; passive and active cathodic protection to counter the effects of corrosion; corrosion protection coatings of embedded reinforcing to limit future interactions between the metal and a corrosive environment, and others.

Plans and specifications have been prepared for hundreds of concrete structures using state-of-the-art materials and construction methods. WJE's research and practical application of cathodic protection systems and experimental laboratory experience regarding specialty concretes, penetrating sealers, coatings, epoxy-coated bars, epoxy-coated prestressing strand, and admixtures sets WJE apart from other firms in the development of construction, rehabilitation, and maintenance procedures for new and older reinforced and prestressed concrete structures. Three noteworthy concrete polymer overlay bridge projects are highlighted below:

Iowa Department of Transportation- WJE completed a detailed investigation of representative units of the 70-year old, double deck concrete structure. The purpose of the study was to assess current conditions and make recommendations for replacement or rehabilitation.

Based on the findings of the investigation, a decision was made to reconstruct Wacker Drive. It was also decided that the viaduct will be rebuilt using high-performance concrete (HPC), both in precast and cast-in-place applications. For this project the primary characteristics for the HPC mix was defined as follows: early age strength of 2,500-3,000 psi in 12-16 hours; ultimate strength of 6,000 psi at 28 days; good workability, placeability, and finishability; and a service life of 75 years in a harsh environment subjected to deicer salts.

To achieve superior long-term durability, careful selection of materials and construction details was necessary for the precast deck sections as well as for cast-in-place components and interfacing materials. To achieve these goals, the team of WJE and subcontractor University of Illinois at Chicago (UIC) was assembled and hired to evaluate HPC mixes and develop a program designed to identify high-performance materials and details, verify their effectiveness, develop construction specifications, minimize the risk of deck cracking, and monitor actual performance.



Ford Parkway Bridge (2010 - MnDOT) - Located in Minnesota, the Ford Parkway bridge showed signs of deterioration from more than seven decades of exposure to a harsh northern climate. Deterioration was most prevalent at crack locations on the bridge deck, floor beams, and spandrel columns, and especially near expansion joints. WJE was retained to conduct a structural investigation of the bridge and determine the most cost-effective means for improving and extending the life of the structure, while maintaining its historic character.

Rehabilitation solutions included: Modifications to floor beam brackets to allow deck widening to accommodate pedestrian traffic behind a vehicular barrier and bicycle traffic on the shoulders; replacement of the deteriorated deck with a new deck, composite with original deck for greater strength and durability; and to protect the structure from moisture and chloride contamination, WJE designed the new deck to eliminate two thirds of the deck expansion joints and relocate the remaining joints away from the floor beams while minimizing the risk of cracking.

Scott Street Bridge (2004) - The Missoula, MT County Department of Public Works retained WJE to complete a corrosion study of the Scott Street Bridge in Missoula, MT for the purpose of determining rehabilitation needs for this multi-span steel girder bridge with cast-in-place deck and overlay. The work also included corrosion studies of the substructure elements. The bridge has experienced corrosion damage to embedded reinforcing steel at crack locations on the decks and due to failures in expansion joints which has allowed moisture to penetrate to the substructure below. Damage to the original concrete deck and overlay was also observed due to water infiltration and chloride-induced corrosion of embedded reinforcing steel.

Field and laboratory work included corrosion testing using half-cell potential and linear polarization techniques, delamination surveys, concrete cover measurements, crack mapping, and sample removal for chloride ion testing and concrete petrography. Using corrosion prediction modeling techniques, WJE as able to predict future bridge performance and provide the bridge owner with sound recommendations for repair and/or replacement based on the damage conditions of each individual bridge span.

WJE's Northbrook Laboratories

WJE's Janney Technical Center (JTC) is named after WJE founder Jack Janney. Composed of both engineers and scientists, the JTC provides advanced testing and forensic capabilities to solve the most technically challenging problems in connection with structures, construction materials, and manufactured components. After half a century and more than 125,000 assignments, JTC engineers and materials scientists have successfully completed investigative, testing, and repair projects involving virtually every type of construction material, structural system, and architectural component. The JTC's 70,000-square-foot state-of-the-art testing and applied research facility (built in 2018) includes wet chemical, petrographic, metallurgy, concrete and mortar, structural testing, and analytical chemistry laboratories as well as environmental exposure chambers.

JTC personnel are recognized leaders in their fields and are active participants in standards development and industry organizations. The multi-disciplinary nature of our team of experienced scientists and engineers enables WJE to offer extensive testing and investigation capabilities to characterize materials, determine root causes of problems, and evaluate performance. The JTC performs tests to determine specification compliance, simulate performance under field conditions, understand failure mechanisms, generate fundamental engineering properties, and assess service life to meet the needs of various types of clients. Our services extend beyond our laboratories, and it is common for JTC personnel to take our expertise to the field and conduct specialized testing on site. From the laboratory to the job site, from engineering to chemistry to physical sciences, JTC professionals develop and test new approaches and create innovative solutions for the built world.

The JTC maintains an International Accreditation Service (IAS) laboratory accreditation. The IAS is a subsidiary of the International Code Council-Evaluation Service (ICC-ES). The ICC is responsible for producing the International Building Code (IBC) and the International Residential Code (IRC). The ICC-

ES, a subsidiary of ICC, is a nonprofit, public-benefit corporation that performs technical evaluations of building products, components, methods, and materials. The JTC operates the laboratory and testing using a quality system and manual written following the ISO 17025, "General requirements for the competence of testing and calibration laboratories".

JTC's laboratory is also accredited by the American Association of State Highway and Transportation Officials (AASHTO) for testing concrete, cement, and aggregates (www.aashtoresource.org). The AASHTO accreditation program utilizes onsite assessments and proficiency sample testing to evaluate laboratories. The laboratory meets the requirements of AASHTO Standard Practice R18 "*Standard Practice for Establishing and Implementing a Quality System for Construction Materials Testing Laboratories*". The laboratory also performs concrete and cement proficiency sample testing through the Cement and Concrete Reference Laboratory (CCRL) and performs aggregate proficiency sample testing through the Aggregate Materials Reference Laboratory (AMRL).

The two WJE laboratory technicians, working on this project, maintain the following certifications: ACI Concrete Field Testing Technician - Grade I; ACI Concrete Laboratory Testing Technician - Grade I; and ACI Concrete Laboratory Testing Technician - Grade II.

Reference Materials

WJE maintains a comprehensive physical and online library, with nearly 35,000 items in the library collections of the Main Library and the unit libraries. The collection consists of periodicals, books, codes, standards, CD-ROMs, DVDs, and WJE company reports. A number of electronic resources available through the Library's intranet page provide immediate access to particular items, such as WJE authored articles and a wide variety of online subscriptions.

ITEM 12: COST ESTIMATE

The following two tables depict the estimated total number of hours for each Item and the hourly and expense costs for each Item. Costs for WJE staff are determined using staff-specific direct costs, combined with company-average overhead, general and administrative costs, and salary benefits computed in accordance with our standard accounting procedures. WJE overhead rates have been audited by the public accounting firm of FGMK, LLC, and are based upon actual expenses of fiscal year 2018 (the most recent available). These documented rates were submitted on Montana's eMACs for this project. A fixed fee of 15% is included in the hourly rate for WJE staff. The selected fixed fee is equal to the fixed fee used during WJE's work from 2016. The costs associated with each item includes the costs for monthly progress and Task reports. The monthly progress reports are budgeted at $1,500 per report. The total cost associated with the Oral Presentation, including hourly rates and expenses, is included in ***Item 4.5***, Page 9, costs and is budgeted at $3,500.

Effort By Tasks (Hours) - MDT - 313162
Bridge Deck Cracking Consultant Services

Principal Staff Members	Role in Study	% Time over Contract Period	Hours						
			Item 4.1	Item 4.2	Item 4.3	Item 4.4	Item 4.5	Item 4.6	Total Hours
P. Krauss	Project Advisor / Materials Engineer	2.8%	5	2	2	12	4	18	43
B. Merrill	Project Advisor / Structural Engineer	1.2%	4	2	2		2	8	18
T. Nelson	Project Manager / Materials Engineer	9.4%	8	2	4	90	5	35	144
M. ElBatanouny	Structural Engineer	8.8%	4			92		38	134
E. Nadelman	Material Scientist	10.8%	24	16	8	64	12	42	166
E. Rahmani	Structural Analyst	15.4%	12		2		200	22	236
L. Zegler	Laboratory Technician	0.5%					8		8
R.Schulman	Field Technician	7.2%				110			110
M.Haddad	Laboratory Technician	1.0%					16		16
Project Totals			57	22	18	368	247	163	875

Budget Detail - MDT - 313162 (updated 01/13/2020)

			Item 4.1		Item 4.2		Item 4.3		Item 4.4		Item 4.5		Item 4.6		Total	
(a) Salaries and Wages																
Name	*Role in Study*	*Direct Hourly Rate**	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*	*Hours*	*Cost*
P. Krauss	Project Advisor / Materials Engineer	$82.08	5	$ 410.40	2	$ 164.16	2	$ 164.16	12	$ 984.96	4	$ 328.32	18	$ 1,477.44	43	$ 3,529.44
B. Merrill	Project Advisor / Structural	$64.93	4	$ 259.72	2	$ 129.86	2	$ 129.86	0	$ -	2	$ 129.86	8	$ 519.44	18	$ 1,168.74
T. Nelson	Project Manager / Material	$59.60	8	$ 476.80	2	$ 119.20	4	$ 238.40	90	$ 5,364.00	5	$ 298.00	35	$ 2,086.00	144	$ 8,582.40
M. ElBatanouny	Structural Engineer	$46.71	4	$ 186.84		$ -	0	$ -	92	$ 4,297.32	0	$ -	38	$ 1,774.98	134	$ 6,259.14
E. Nadelman	Material Scientist	$41.95	24	$ 1,006.80	16	$ 671.20	8	$ 335.60	64	$ 2,684.80	12	$ 503.40	42	$ 1,761.90	166	$ 6,963.70
E. Rahmani	Structural Analyst	$40.63	12	$ 487.56	0	$ -	2	$ 81.26	0	$ -	200	$ 8,126.00	22	$ 893.86	236	$ 9,588.68
L. Zegler	Laboratory Technician	$41.06	0	$ -	0	$ -	0	$ -	0	$ -	8	$ 328.48	0	$ -	8	$ 328.48
R.Schulman	Field Technician	$39.42	0	$ -	0	$ -	0	$ -	110	$ 4,336.20	0	$ -	0	$ -	110	$ 4,336.20
M.Haddad	Laboratory Technician	$29.61	0	$ -	0	$ -	0	$ -	0	$ -	16	$ 473.76	0	$ -	16	$ 473.76
Subtotal			57	$ 2,828.12	22	$ 1,084.42	18	$ 949.28	368	$ 17,667.28	247	$ 10,187.82	163	$ 8,513.62	875	$ 41,230.54
(b) Borrowed Personnel - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(c) Consultants - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(d) Subcontracts - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(e) Capital Equipment - None Anticipated																
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(f) Materials and Services																
Task 4.4b - Equipment Rental (Data Acquisition System)				$ -						$ 8,912.50		$ -		$ -		$ 8,912.50
Task 4.4b - Solar Panels 1										$ 1,500.00						$ 1,500.00
Task 4.4b - Upgrade Colder Weather Data Loggers										$ 662.50						$ 662.50
Task 4.4b - Internal Relative Humidity Equipment										$ 5,850.00						$ 5,850.00
Task 4.4b - Strain Gages x 12										$ 3,650.00						$ 3,650.00
Task 4.5a - Shipping of Raw Materials										$ 1,200.00						$ 1,200.00
Task 4.5a - Unit Rates for Lab Testing										$ 6,500.00						$ 6,500.00
				$ -		$ -						$ -		$ -		$ -
Subtotal				$ -		$ -		$ -		$ 28,275.00		$ -		$ -		$ 28,275.00
(g) Communications and Shipping - None Anticipated																
																$ -
Subtotal				$ -		$ -		$ -		$ -		$ -		$ -		$ -
(h) Travel																
Item 4.4a (Airfare, Hotel, Car and Meals)				$ -				$ -		$ 5,230.00		$ -		$ -		$ 5,230.00
Item 4.4b (Airfare, Hotel, Car and Meals)										$ 5,850.00						$ 5,850.00
Item 4.6 (Airfare, Hotel, Car and Meals for Oral Presentation)				$ -		$ -				$ -		$ -		$ 1,425.00		$ 1,425.00
Subtotal				$ -		$ -		$ -		$ 11,080.00		$ -		$ 1,425.00		$ 12,505.00
(i) Employee Benefit Plan & Payroll Taxes				$ 1,908.13		$ 731.66		$ 640.48		$ 11,920.11		$ 6,873.72		$ 5,744.14		$ 27,818.25
	Rate:	67.47%														
(j) General Overhead & FCCM				$ 4,095.68		$ 1,570.46		$ 1,374.75		$ 25,585.75		$ 14,754.00		$ 12,329.42		$ 59,710.07
	Rate:	144.82%														
(k) Fixed Fee				$ 1,324.79		$ 507.98		$ 444.68		$ 8,275.97		$ 4,772.33		$ 3,988.08		$ 19,313.83
	Rate:	15.00%														
PROJECT GRAND TOTALS			**57**	**$ 10,156.73**	**22**	**$ 3,894.52**	**18**	**$ 3,409.18**	**368**	**$ 102,804.12**	**247**	**$ 36,587.87**	**163**	**$ 32,000.26**	**875**	**$ 188,852.68**

ITEM 13: REFERENCES

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